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TECHNICAL COMMUNICATION No. 15

SPRING FROST DAMAGE IN ORCHARDS AND ITS POSSIBLE PREVENTION

September, 1945

Price 1/6

Published by the Imperial Bureau of Horticulture and Plantation Crops, East Malling, Kent, England, and obtainable from I.A.B., Central Sales Branch, Agricultural Research Building, Penglais, Aberystwyth.

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CONTENTS

PAGE

FOREWORD. By Professor E. J. Salisbury, C.B.E., D.Sc., F.R.S., Director of the Royal Botanic Gardens, Kew 3

INTRODUCTION 4

I. PHYSIOLOGICAL ASPECTS OF FROST INJURY 5

II. INTERNAL AND EXTERNAL FACTORS AFFECTING FROST RESISTANCE 5
1. Pollination 5
2. Anatomical structure 5
3. Rootstocks 5
4. Critical temperatures 5
5. Microclimate 6
6. Wind movement 7

III. METHODS AND APPARATUS FOR PREVENTING DAMAGE 7
1. Breeding 7
2. The application of mineral fertilizers 8
3. Prolongation of dormancy by spraying 8
4. Spraying to induce parthenocarpy 9
5. Spraying and injecting various substances 9
6. Spraying with water 9
7. Irrigation 10
8. Infra-red rays 10
9. Wind machines or blowers 10
10. Central heating 10
11. Soil heating 11
12. Orchard heating 11
(*a*) The use of heaters 11
(*b*) Appliances 12
13. Smoke screens and chemical mists 14

IV. THE PRESENT POSITION 15

V. SUGGESTIONS WITH REGARD TO FUTURE WORK 16
1. Meteorological 16
(*a*) Frost 16
(*b*) Wind 16

2. Topographical 16
(*a*) Frost holes 17
(*b*) Broad valleys or plains 17
(*c*) Hilltops 17
3. Pomological 17
(*a*) Breeding 17
(i) *For late blossoming* 17
(ii) *For resistance* 18
(*b*) Cultural methods 18

VI. SPECIFIC CONTROL MEASURES 18
1. Orchard heating 18
2. Production of smoke clouds 19

ACKNOWLEDGEMENTS 19

REFERENCES 20

FOREWORD

The problem of frost damage to orchards is one of the more important of the many aspects of microclimatology that play a significant part in determining the success or failure of cultivated crops.

In summarizing existing information on this subject, the Imperial Bureau of Horticulture and Plantation Crops has performed a useful service. It is only by understanding something of the complex interaction of topographical, biological, meteorological and other factors, that together determine whether frost damage occurs or not, that the grower can take advantage of such help as science can afford or himself co-operate towards the increase of our knowledge.

The fruit-farmer who expects a simple solution to be provided for his fruit problems is apt to forget that fruit damage depends partly on where and how he plants his orchard, partly on the varieties he has chosen, as well as on climatic conditions obtaining in his area during a particular season.

It is no use blaming the weather if he has foolishly chosen to plant up a frost pocket or to grow varieties with no regard either to their climatic tolerance, or to their particular rhythm of development in relation to the normal climate of the area concerned. The present account should do much to help the intelligent grower to apprehend what of the complex of circumstances that lead to frost damage can be avoided or diminished by taking thought and appropriate action and what constitute the real risks that are as yet more or less outside his control. If on the one hand we have regard to the adage " nothing venture, nothing have ", we remember on the other the behest to " look before you leap ", and it is the function of science in relation to agriculture to discover the causes which produce effects and thus enable us either to exert control or to define the limits of what is outside our guidance. Only then can we exercise our judgment as to practicable control or the magnitude of unavoidable risks.

E. J. Salisbury.

INTRODUCTION

Each spring in the deciduous fruitgrowing areas of the Empire the chief interest for a couple of months is whether late frosts will occur of sufficient severity to damage fruit crops.

Prediction is much easier in some countries and areas than in others, and where a fruitgrower is certain of the incidence of such frosts he will not grudge expenditure on heaters, or smoke producers or wind machines or whatever gives the most effective protection, and he will insist on investigations being made to determine the most efficacious and economic control measures.

In England particularly, with its maritime climate, the problem is complicated by the uncertainty of severe frost occurrence, so that the fruitgrower must decide, not only whether he can efficiently protect his fruit from damage, but also whether it is economically wise to lay out his money on apparatus which may only be wanted one year in four or five.

At East Malling Research Station, near Maidstone, England, there have only been six seasons in thirty years in which frost has occurred of sufficient severity to do serious damage to apple blossoms, and the apple, pear and plum yields of the station may be taken as representative of those of the average, well managed commercial orchard. The first fourteen years of the Station's existence were entirely free from frost damage. Meteorological data for the British Isles over the past sixty-four years show a series of low May temperatures between 1897 and 1907, succeeded by a period of warmer temperatures with their peak between 1911-20 and declining to the present series of lower May temperatures.

It may, therefore, be useful to discuss briefly what work has been and is being done, paying particular attention to methods which have under certain circumstances proved useful, and to consider what steps seem most likely in the future to remove eventually this recurrent bugbear.

Before we can hope to work out efficient methods of frost protection it is essential to understand the material which we want to protect and to have a clear idea of the physiological phenomena associated with frost in plant tissues or, in other words, what exactly happens in a plant assailed by frost.

Next we should know what factors, internal and external, predispose to damage or security from damage.

Only then can we turn with some assurance to the provision of methods and apparatus for warding off the danger.

SPRING FROST DAMAGE IN ORCHARDS AND ITS POSSIBLE PREVENTION

I. PHYSIOLOGICAL ASPECTS OF FROST INJURY

The literature on the physiological aspects of frost injury and resistance, which is surveyed at some length by Levitt (1941), is very extensive, but the broad picture, as it affects practical issues, is not abstruse.

Death of cells from frost appears to be usually the outcome of one of two types of injury or sometimes a combination of both. The cause of death is often an irreversible change in the living colloidal substance of the cells or it may be due to a rupture of the protoplasts. Rupture of the protoplasts may be a consequence of the formation of ice crystals or result from the too rapid swelling of the cell contents unsupported by the cell-wall, after its dehydration and contraction due to freezing.

Irreversible precipitation of the protoplasmic colloids may result from a variety of causes as, for instance, from the low temperature itself or from dehydration, but internal conditions such as, for example, the degree of acidity of the cell sap or the amount of sugar in solution can greatly influence the susceptibility of the protoplasm to become precipitated. As different varieties of the same species may vary greatly in the acidity of their cell sap or their sugar content two strains might differ markedly in their frost resistance, even though in every feature of external appearance they seemed identical. Conditions, which tend to protect the protoplasm against irreversible precipitation, often tend to increase the degree to which it can retain water, so that the unfreezable water held by the colloidal contents of the cell may be greater in a hardy than in a non-hardy plant. Nevertheless it is true in general that hardy plants contain less water than tender ones, just as the young and soft shoots of an individual tree are more susceptible than the older, ripened twigs. The two features are in no sense contradictory because the one is more particularly associated with risks of irreversible precipitation, the other with risks of protoplasmic rupture.

II. INTERNAL AND EXTERNAL FACTORS AFFECTING FROST RESISTANCE

1. POLLINATION

Modlibowska (1945) writing of frost injury to secondary flowers quotes Chandler (1942) for the general acceptance of the fact that an open flower is more resistant to low temperature than a young fruitlet of the same variety. She further recalls that West and Edlefson (1921) found that, when the fruit is setting, the injury from frost is from 5 to 10 per cent greater than when the flowers are in full bloom. Field (1945), however, is of the opinion that pollinated blossoms are less susceptible than those not pollinated.

2. ANATOMICAL STRUCTURE

In Russia Bibikova (1941) found with a series of eight varieties of apples, whose relative powers of frost resistance were known, that the larger the stomata and cells in the leaves the greater was the frost resistance, particularly in young plants.

Field (1939) considers that it is not so much the anatomical structure of the plant which gives resistance as some quality in the cell protoplasm.

3. ROOTSTOCKS

Rootstocks are potentially important inasmuch as they may influence the time of flowering and so susceptibility to frost damage. (Hatton and Grubb, 1925.)

4. CRITICAL TEMPERATURES

There is considerable difference of opinion among workers as to danger temperatures, a matter of some importance, since too early or too late lighting of orchard heaters is in either case an unnecessary expense.

This divergence of opinion seems to indicate that there is no one temperature which is universally fatal to fruit blossom. As regards apples, of six American authorities three regard 27°F. and three 25°F. as the danger point for buds showing colour ; for open blossom opinion is equally divided between 28° and 29°F., while during setting temperatures from 30° to 28°F. all have advocates.

These are field data. Critical temperatures decided by laboratory methods should be lower because of the differences between air temperatures and plant temperatures under the radiation conditions which accompany most frosts, and the precise determination of killing points might not be of direct application in the orchard.

Varietal differences in susceptibility have been observed. To give one instance. Field (1939 and 1942) working at East Malling with refrigerated blossoms found varietal differences in susceptibility to damage. For instance Bramley's Seedling and Cox's Orange Pippin were damaged after two hours at 29°F., or one hour at 28°F. or half an hour at 27° or 26°F., whereas Worcester Pearmain required four hours at 29°F. or two hours at 28°F., but at 26°F. injury occurred in half an hour as with the other two.

The importance of length of exposure at given temperatures needs further investigation.

Degrees of cold resistance must, it is evident, also depend on present and previous external conditions, though exactly what those conditions may be is a matter on which little is known except that they vary with the orchard. Rapid thawing is not in itself injurious despite common opinion to the contrary.

Field (1942) confirms this, but shows that the rate of cooling can affect damage, i.e. a sudden fall of temperature may do more damage than a gradual one. She also shows that short periods of alternate freezing and thawing do less damage than continuous freezing even at temperatures as low as 26°F. The effect of light on frozen tissue has been insufficiently studied. Light is known to increase permeability and it may be conceived of as preventing the return to the cells of water which has been withdrawn on freezing, thus causing injury to tissues, which otherwise would recover their normal state. (Gardner, Bradford and Hooker, 1939). Chandler (1928), however, says that he has never been able to find that blossoms on the sunny side of the tree are more damaged than those away from the early morning sun.

5. MICROCLIMATE

In Germany the possibility of improvement of microclimatic conditions in the plantation by alterations in the landscape has also been envisaged. Kessler (1935), taking as an example an actual named vineyard, suggests the removal of a strip of woodland bounding the lower end of the vineyard, replacing the hedges above the vineyard by a plantation of forest trees and the draining of an adjoining marsh. On the side receiving the prevailing wind he proposes windbreaks. Storage ponds should be formed below the vineyard on the assumption that they would ensure a considerable warming of the cold air. It is not known whether these suggestions were carried out.

Cornford (1939a), also quoting Ramdas (1935), notes that the lowest minimum temperatures occur over grass. The air above bare soil is relatively warm, the temperature recorded at a height of 3 ft. often being 6°F. higher than that over land under grass.

Rogers (1943), conducting experiments at East Malling, found that a layer of straw on the ground, such as it is customary to place round strawberries, has the effect of insulating the heat radiation from the ground to an extent that may make, under certain conditions when the plants are in bloom, all the difference between frost damage and no damage. The thickness of the layer of straw makes no difference to the insulation. In these experiments the average minimum temperature recorded above bare ground was 7°F. higher and that below the straw 13·3° higher than that above the straw. The effect of this was strikingly illustrated in the spring of this year, 1945 (Rogers, 1945) when the blossom of a strawberry bed, which had been strawed unusually early, was heavily frost-damaged while neighbouring unstrawed beds were scarcely harmed.

In a survey made by members of the East Malling staff of the severe frost damage experienced in Kent on the night of 16th-17th May, 1935 (Bane, 1936), the various contributory factors were considered. The evidence as regards effect of manuring was conflicting. Both

good and bad effects of windbreaks were noted, as was also variation in susceptibility to damage among varieties. But in particular the enquiry emphasized the protection afforded to plantations by proximity to large rivers or the sea and by height of plantation relative to surrounding ground. Height in itself afforded no protection, nor were all low lying plantations subject to severe damage.

6. WIND MOVEMENT

The effect of climate on horticulture and particularly the relation of winds to frost incidence has received some attention in the past. Cornford (1938) notes that so-called downhill or katabatic winds have been discussed by the following, among other, authors :—Bedford and Pickering (1919), Brunt (1936), Daniell (1826), Heywood (1933), Marvin (1914), Newnham (1918) and Whitley (1868).

In 1935 as a result of a resolution passed at a Conference on Frost Damage called by East Malling Research Station, C. E. Cornford (1938, 1939a, 1939b, 1939c) was appointed under a grant from the Ministry of Agriculture to make preliminary studies of the cause and prevention of frost damage. Headquarters were established at East Malling, hence much of the work is influenced by the climatic conditions of that neighbourhood. Cornford's work was largely directed to the study of katabatic or downhill winds, which on otherwise still radiation nights may cause large quantities of cold air to accumulate on low lying ground. Tests were also made with orchard heaters to find the best technique for estimating their efficiency. Considerable knowledge was acquired relating to the conditions affecting the direction of katabatic winds, but much remains to be done before results of practical value to the orchardist can be expected. Cornford suggests future work along the following lines. A study of: (1) The relationship between altitude and temperature, i.e. the number of degrees that must be allowed for each 100 ft. of altitude. Anomalous temperature distribution was shown to be common. It is important to know how common, for if it can be shown on, say, 50 per cent of frosty nights that the valley bottom is not the coldest place, there is less objection to planting fruit there. The cause of anomalous temperature distribution also remains to be discovered. (2) Air temperature profiles in various fruit crops. Temperatures recorded only at 3 ft. above ground level appear to vary with the crop. (3) Air movements over level land and those on the leeward side of steep slopes. Each class of topographical site is associated with a distinctive air movement. For instance, air seems to become motionless and therefore suited for orchard heating at the bottoms of large valleys, but not of smaller and higher valleys. (4) The influence of vegetation and air movement on minimum temperatures on hill tops. Fruit on hill tops is often as much damaged as that in the neighbouring valleys for reasons not determined. (5) Wind frost conditions. Wind frosts may do great damage. No microclimatological work seems to have concerned itself with wind frosts and, until something is known of them, control methods are not likely to succeed. A visit to Long Ashton Research Station, Bristol, in the summer of this year (1945) shows the disastrous effects on fruit on both high and low ground of a severe wind frost in late spring. Incidentally it is interesting to note that, whereas top fruits have been more or less wiped out, black currants, a crop generally most susceptible to spring frost damage has escaped lightly. (6) Effect of nature of soil on the temperature of the air above it. Not only vegetation but differences in the nature of bare soil are able to influence air temperature on frosty nights.

III. METHODS AND APPARATUS FOR PREVENTING DAMAGE

The search for methods by which spring frosts may be combated has covered a wide field. Some of the directions in which research has proceeded are indicated below.

1. BREEDING

At East Malling Research Station and the John Innes Horticultural Institution work on the breeding of frost resistant types is in progress. Characters required in such types are late flowering to avoid the frost period, and therefore quick ripening, and/or, most desirable of all, increased resistance of the blossom and young fruit to frost damage. These traits, moreover, must be combined with all the other qualities which go to make a commercial apple

acceptable to the public and without idiosyncrasies in the orchard. The evolution and establishment of such types may well take a lifetime unless, as seems conceivably possible, a quick test for frost resistance can be evolved by the physiologists or biochemists.

Work has been in progress in Germany (Schmidt, 1943). Here the use of the hardy wild types *Malus baccata, M. prunifolia* and others has been abandoned owing to the difficulty of eliminating the bad characteristics of the wildings. Instead, large collections of seedlings are being grown from crosses between horticultural varieties and from open pollination, the buds and blossoms being tested in cold chambers for frost resistance. In most continental countries frost hardiness of the whole tree has also to be considered, a problem that causes little worry in England.

2. THE APPLICATION OF MINERAL FERTILIZERS

The application of certain mineral fertilizers, chiefly ammonium nitrate, in autumn according to Semyakin and Moroz (1940) increased the hardiness of tangerines and grapefruits against cold (not frost) in Southern Russia.

Lawless and Camp (1940) found no differences in frost hardiness of citrus attributable to N, P, or K, but they did find that any deficiency and particularly that of Cu and Mg predisposed trees to cold injury.

Rohde (1942) adduces evidence to show that the cold resistance of a number of staple crops including pears, plums and vines is increased by the presence in the soil of K, P, Mg, Fe, Cu and Cl and diminished by Ca, Mn, Na, B, S and Si. Any environmental features which tend to increase potash in the plants, e.g. low temperature, lack of water, bright light and minerals which favour the intake and effects of potash, increase cold resistance.

Gardner, Bradford and Hooker (1939) are sceptical as to the value of nitrate manuring in this respect in U.S.A.

In this country observations on the subject have been, though interesting, largely incidental.

Hoblyn and Bane (1934) in a manurial trial at East Malling noted the effect of manuring on frost damage to fruits of Bramley's Seedling apples. In 1933 severe frosts occurred when the blossom buds were still closed and as a result there was considerable russeting round the eyes of the fruit. Examination of the crop from trees on No. IV rootstock, the only rootstock available for this purpose, showed that, while on the Nil and N plots the percentage of affected fruits were 39 and 36 respectively, on the K and NK plots the figures were only 21 and 19 per cent. In the absence, however, of detailed records of time of blossoming on trees receiving the different treatments it was impossible to decide whether the variation in damage was due to the manurial factor or to some difference in the texture of the skin of the fruitlet.

Incidentally, it is interesting to note that Wallace (1931 and 1933) has found in pot experiments that the omission of K usually advances the opening of blossom buds, while deficiency of N delays it. The same author (1931) and (1926) has also found that K-deficient fruits in store and K-deficient growing vegetables are especially liable to damage from low temperatures.

Roach (1940) records an instance of trees treated for chlorosis the previous summer by the injection of iron as ferrous sulphate which were not only cured of chlorosis but also bore a heavy crop the following year, although the spring frosts of 1938 destroyed all the crop of the untreated trees in the plantation. The inference is that frost resistance can sometimes be increased by improving mineral nutrition.

This inference is further supported in a private communication from Roach (1945) in which he records observations on a hydrangea injected with iron in the summer. The areas of the leaves affected by the iron remained uninjured by an autumn frost which damaged the areas on the same leaf not entered by the iron.

3. PROLONGATION OF DORMANCY BY SPRAYING

Hitchcock and Zimmerman (1943) in the U.S.A. delayed the opening of flower buds of apple, cherry, peach, pear and plum from a few to 14 days by spraying in the previous July with α-naphthaleneacetate 200mg./l. Apple was more resistant to treatment than most fruits. Plums responded the best.

In the United States Sell and others (1942 and 1944) noted that the dormancy of tung trees (which suffer much from early frosts) was markedly prolonged by the application to the buds by means of a small brush of 0·3 % α-naphthalene acetamide or indole-3-acetic acid in lanolin. The lanolin carrier was ineffective by itself in 1942, but in 1944 it maintained the buds for 12 days at a stage of dormancy not injured by a temperature of 28°F. The treatment killed 7% of the buds. The treatment with the chemicals in lanolin gave a more prolonged dormancy but killed more buds. Injection of the bud sheaths and spraying with the chemicals was ineffective. The method of application is regarded as impracticable in orchard work.

At Merbein Research Station, Australia, and in South Australia and New South Wales 11 days delay in bud burst was obtained with dormant vines sprayed with a common summer spraying oil (viscosity 60-70 R1 at 100°F.). Length of delay increased with concentration of the oil up to 40%. In a dry season similar results were obtained with sprays applied 8, 5 and 2 weeks before bud burst, but in a wet season application 5 weeks before bud burst resulted in the greatest delay. The treated vines were normal by harvest and yield did not suffer. In severe frosts in 1941 14% of untreated buds were killed whereas on vines sprayed with 5 and 15% oil only 7 and 1·2% respectively were killed (Walters and Spicer, 1943).

In Russia Eremeev (1936) prolonged dormancy in deciduous fruit trees by spraying with light oils, including sunflower seed oil.

4. SPRAYING TO INDUCE PARTHENOCARPY

The evidence that some plants will naturally produce fruits parthenocarpically, i.e. without pollination or when pollination has failed, and that some plants can be induced to set fruit parthenocarpically under chemical stimulus (Gustafson, 1942) suggests the possibility of using growth substances to induce fruit formation in fruits damaged by frosts. Sereisky in the Ukraine (1938) obtained seedless fruits in the pear variety Caucasicus by treating the flowers with indole-acetic acid. More recently Swarbrick (1945) has been experimenting with apples and pears at Long Ashton. A severe frost occurred on the night of 30th April-1st May, 1945, by which time apples and pears were set and developing rapidly. The frost killed the embryos and blackened the centres of the fruit. A number of trees of apple and pear were sprayed on 8th May with a mixture of growth-promoting substances known to be effective on tomato. Cox's Orange Pippin trees did not respond to treatment and all the fruits fell off as did those of the untreated Millers Seedling. But Conference pears and Millers Seedling apples responded and in mid-July the position on the treated trees was as follows : All the fruits remained on the trees, the apples being about $1\frac{1}{4}$ inches in diameter, sweet but flavourless and having stopped growth, while the pears were about the same size but were still growing. The pears were not so big as they would have been, had they been pollinated or had they been frosted and continued growth. Though we do not yet know the right material or optimum dosage for apples and pears, Swarbrick feels that it is only a matter of time before suitable materials are found which will be as effective on apples and pears as β-naphthoxyacetic acid has proved on tomato.

5. SPRAYING AND INJECTING VARIOUS SUBSTANCES

In Germany Schlenz (1939) claimed to have obtained some resistance by dusting the inflorescences with powdered lime, also by spraying with milk of lime, and with soft soap solution plus a spreader.

Field (1939 and 1942) at East Malling found that the injection of 5% glycerine into shoots of blackberry gave good resistance at 26°F. and complete resistance at 28°F. The controls were severely damaged. Injections of dextrose and of urea were ineffective. Later she found that spraying apple blossom with dilute glycerine, 25 c.c. glycerine in 75 c.c. water, resulted in diminished susceptibility to frost damage up to 3 days but no longer.

The difficulty of determining the optimum strength, timing and number of applications of the sprays envisaged in Sections 3-5, above, should not be underestimated.

6. SPRAYING WITH WATER

Spraying with water during a frost has been experimentally tried on many occasions. In an experiment with apricots in Utah the only blossoms killed were those sprayed (Gardner, Bradford and Hooker, 1939).

In France Mercanton (1939) sprayed dahlias and tender vegetables with water at 30°F. in severe weather, covering them with a thick sheet of ice under which the plant remained unharmed.

Kessler (1936) after experiments in 1936 says that the artificial rain must start at the same time as the frost and that it must continue throughout the frost, so that there is always some moisture on the parts to be protected. The continual freezing of the moisture generates heat, for instance, with a temperature of 20°F. outside, the temperature of the buds under the ice formed by the artificial rain was about 31°F. The plants were strawberries, tomatoes and potatoes. Tree fruits are not mentioned. He concludes that orchard heating is still the most practicable way.

7. IRRIGATION

Schoonover and others (1939) found that irrigation before a frost can provide protection. The process has to be repeated each night of a frost and has, of course, many disadvantages even when possible.

8. INFRA-RED RAYS

A report is given in the California Citrograph (Anon, 1939) describing a visit to a lemon orchard of 2½ acres in which the use of infra-red, therapeutic 260 watt lamps with reflectors is said to have prevented frost damage on lemons at a recorded air temperature of 23·5°F. (The lemon is one of the most susceptible citrus fruits being affected at 38°F., at which temperature it shows premature ripening.) The lamps were strung on wires 12 ft. (16 ft. would have been better it is thought) above the centre of alternate rows. Spacing between the lamps was 20 by 40 ft. and they were staggered so that light covered every part of the tree.

In 1939-40 thirteen infra-red lamp installations were reported to be in use in California. But, despite this, tests at the California Agricultural Experiment Station, Davis (Gordon and Brooks, 1940), showed no evidence of infra-red lamps having afforded any protection or increased resistance to frost.

9. WIND MACHINES OR BLOWERS

The efficiency of wind creating machines is open to doubt, but they are sometimes used in California.

A survey of wind machines under frost conditions by Thompson (1937) shows one orchard in which the wind machine raised the temperature 3 or 4°, so that the temperature was 20°F. in the orchard and outside 16°F. Some other orchards equipped with wind machines—but without thermometer records—looked better than those unequipped, while others looked worse.

Moses (1938) describes and illustrates some of these machines, of which about 150 were in use in California citrus and walnut orchards in 1938. It is thought that protection is afforded by the drawing down of the warm ceiling air and its mixing with the colder air round the trees. The author thinks that (1) under conditions of temperature inversions of 10°F. at 100 ft. elevation air temperature in orchards may be maintained at 3° higher with a blower mounted on a tower 40 to 50 ft. high. (2) Blowers of 75 h.p. size will not handle over 10 acres except under conditions of favourable air drainage. Furnaces situated at the base of the blower burning 20 to 40 gal. of oil per hour are mentioned but their performance is not given. The idea is that that they should blow warmed air over the trees. A blower described consisted of a large propeller, aeroplane type, 12 ft. in diameter, directly connected to a 425 h.p. engine mounted on a platform 50 ft. above ground. The platform is geared to the engine and rotates about a vertical axis at a speed of about 15 revolutions per hour.

10. CENTRAL HEATING

The piping of warm air as steam to each tree was tried in U.S.A. (Schoonover and others 1939). It proved impracticable in anything but a dead calm and installation costs were high.

11. SOIL HEATING

It has been suggested that methods used for the electrical heating of the ground below hot beds might be further developed and applied to the protection of low-growing fruit, such as strawberries, gooseberries, etc. A report by Brown and Golding (1942) describes simple and economical equipment for soil heating on a small scale and is worth study. More elaborate apparatus are described from America by Wyman and Nixon (1934). There are of course many possible objections, not the least being the hampering of cultivation by the presence of the cables just below the soil surface. However that may be, the effects of electrical warming of the soil might well form part of any investigation on horticultural meteorology in its bearing on frost protection.

12. ORCHARD HEATING

(a) The use of heaters

In the Californian citrus orchards heating is regularly carried out and is highly organized. Incidentally, oil is very much cheaper there than in England. Work on the improvement of heaters is continuous, the chief aims being elimination of smoke, reduction of soot in the bowl and economy in fuel consumption.

The most successful results so far achieved in preventing low temperatures in orchards, particularly in the U.S.A. have been realized by the use of large numbers of small heaters warming the air itself. In some districts, chiefly citrus, this practice has become a settled part of orchard routine, in others, mainly deciduous, it has been abandoned as being an expensive and by no means infallible insurance. The heaters are useful only within a very narrow range of temperatures. Above or below that range they are either unnecessary or ineffective. Failure to realize this has often led to the instalment of orchard heating equipment where its usefulness could rarely be proved and the resulting disappointment has tended to obscure the circumstances in which it can be of real value.

Some interesting calculations were made by McAdie in the United States Department of Agriculture Monthly Weather Review for 1912 (Gardner, Bradford and Hooker, 1939) which help to show the amount of actual heating any ordinary equipment can secure. With 100 burners to the acre, he says, each using a gallon of oil, about 15,000,000 British thermal units or 3,760,000 (kilogram) calories would be given off, provided combustion were perfect—which it never is. To raise the temperature of the air over an acre to a height of 15 ft. is to heat 653,400 cu. ft. of air. In practice, to maintain the temperature on a still night 1° above the freezing temperature requires 0·252 calories per hour per cu. ft. So that in California, where the average duration of a low temperature is only about seven hours, 1,138,200 calories would be required for a 1° rise over this period and, if a rise of 5° is required, it is evident that more than 5,500,000 calories are needed or more than the full number of heat units in the fuel under perfect combustion.

Practical experience shows (Gardner, Bradford and Hooker, 1939) that a 4°F. rise is a liberal estimate of what may be achieved under ordinarily favourable conditions, which include absence of wind over 6 miles per hour. The height of the ceiling of warm air above the orchard has a profound effect on the efficacy of the heating, for the warmed air from the heaters has to rise, mixing with somewhat cooler air until the mixture reaches a layer of the same temperature, thus the higher the ceiling the greater amount of air must be heated.

Heat from a few large fires is so great that it does not mix readily and rises farther than heat from small fires, being thus rendered less effective for warming the air at lower levels. The radiation heat of these fires, though effective near the fires, diminishes as the square of the distance from the source of heat and so soon becomes ineffective and, further, colder air is drawn in to replace the warmed air driven high aloft and this may disturb the ceiling layers. Whether heating is economically sound depends on local circumstances. An example is quoted by Gardner, Bradford and Hooker (1939). During 1913 to 1922 unprotected apple orchards in the Pecos Valley (U.S.A.) suffered six total and three partial failures because of frost. Protected orchards bore eight full crops during the same period, but the cost of the heating was too great to allow the producers to compete with areas where heating was unnecessary.

In the citrus orchards of California heating is a routine practice, for the crop is valuable, the frost prediction system is highly organized and the frosts are as a rule mild and easily dealt with. In deciduous fruit areas orchard heating is falling into disuse, presumably because it has not paid. In alternate bearing orchards the chance of heating proving profitable is of course diminished. Assuming a damaging frost in half the blossoming seasons and a crop in alternate years, the chance of heating being required to save the crop is 1 in 4 or, if the frost occurs once in 3 years, the chance is 1 in 6.

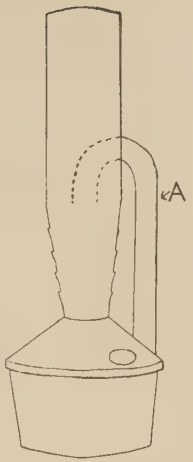
Auchter and Knapp (1929) consider that occasionally a crop may be saved by heating, but that many times the fires have to be lighted unnecessarily and that too often a low temperature may damage the crop in spite of the heaters.

In England Rawes (1935) at Wisley, in an experiment with 200 Harrington heaters distributed over an orchard of 4 acres of bush and half-standard apples interplanted with black currants and strawberries, raised the temperature of the orchard 6°F. above the outside temperature, which at 7 a.m. G.M.T. was registering 12° of frost. The wind, though gusty, did not exceed 6 m.p.h. The heaters were lighted at 10 p.m. and by midnight had raised the temperature 3° above that outside. It is not stated at what time the maximum was reached. The oil consumed was about 400 gallons. Smoke and a deposit of greasy soot would have caused inconvenience in a populous neighbourhood. The heat produced would have been sufficient to protect a crop against the frosts which might be expected in plantations more favourably situated than that at Wisley. In this instance the crop was badly damaged on the two succeeding nights, 18th and 19th May, 5° and 9° of frost respectively, because the orchard could not be heated for lack of oil.

Research on the prevention of frost carried out at East Malling in 1938 (Cornford, 1939b and 1939c) showed that certain elementary precautions should be taken in making experiments to determine the effectiveness of orchard heaters. It was found that, whether the heaters were alight or not, the thermometers in the heated area recorded a higher temperature than that given by a similar thermometer outside it. In this instance the cause was the larger area of long grass exposed to the sky under the outside thermometer, but other unequal conditions might also arise. Such irregularities can be minimized by enclosing each thermometer bulb in a ventilated screen of thin metal. The metal, being thin and a good conductor of heat, is able to pick up from the air as much heat as it loses by radiation and the bulb within is really in a box having the temperature of the air, and hence gives a reliable reading which can be used for accurate comparisons. A bare bulb thermometer exposed to the sky and on bare soil may register several degrees less than a screened one beside it. In carrying out orchard heating trials the thermometers inside and outside the heated area must be screened, placed at the same height above ground and in the same environment, particularly as regards exposed grass. The thermometers inside the heated area must be centrally placed between four heaters or at stated distances from them and should be read simultaneously at intervals of 20-30 minutes. The downhill or katabatic winds must also be considered before setting up orchard heating. Cornford (1939a) during his investigations at East Malling described a simple method of observing these. Even on frosty nights, apparently quite calm, there may be katabatic or downhill winds on sloping lands which will carry the hot air out of heated orchards and decrease the effectiveness of the heaters. It may also be wasteful to use heaters in an orchard of widely spaced bush trees where long grass and weeds are exposed to the sky, since the cold air produced by the exposed grass may neutralize the warmth from the heaters.

(*b*) **Appliances**

Present day orchard heating is usually carried out by means of oil burning heaters of varying degrees of efficiency and smokiness. Smokiness, in fact, can constitute a public nuisance and in California the degree of smokiness permitted has been regulated by legislation. In England, in the Canterbury district of Kent, attempts at orchard heating by the use of crude oil were followed by so many complaints from householders that the Public Health Committee was forced to take action by threatening proceedings under the Public Health Act of 1936 against those who continued to use the method, which was accordingly discontinued.—*Times*, 15th April, 1938 ; *Daily Telegraph*, 22nd April, 1938.



The University of California has made a comprehensive study of orchard heating appliances and claims to have made an important advance by the development of a new type of oil heater known at present as the Return-stack-gas heater, an appliance which deals effectively with the smoke problem and has other advantages (Leonard and Brooks, 1940). In this heater part of the stack gases are returned to the bowl of the heater and mixed with the incoming air and have the same effect in reducing the rate of soot accumulation in the bowl and the smoke output from the heater as the introduction of steam to a coal or oil furnace is known to have. There is also an increased economy in oil consumption because of a compensating change in the composition of the returned stack gases. The heater has a single outside return tube (A) from the centre of the stack to the bowl. The stack gas flows downward in the outside tube because the cooler gases in the tube are heavier than the hot gases in the stack, and because the normal stack draught creates a suction in the bowl which pulls the stack gases through the tube. Reverse circulation is prevented by the downward facing end of the return tube in the stack.

The inverted conical type combustion chamber stack has been found to have a good vortex action in the combustion chamber. Small vortices are set up on each side of the vertical rows of louvers by the air as it enters the combustion chamber, producing turbulence and good mixing of the air with the fuel in the combustion chamber and contributing to the cleaner working of the heater. An inverted combustion cone is preferred because the burning rate is thereby reduced. This heater had a much wider range of burning rates over which it was reasonably smokeless than other natural draught oil heaters. In practice the best results were obtained at rates between 0·5 to 0·9 gallons per hour, whereas in the Rawes English trial the Harrington heaters burnt only 0·25 gallons per hour. Such a heater is also easy to light and extinguish, burns ordinary heater oil, has good radiant energy characteristics and will burn dry without excessive smoking or injury to the bowl.

Kepner (1940) describes an improved automatic regulator for oil heaters, which reduces labour and the smoke nuisance.

Grainger (1939, 1940), investigating in England the internal temperature of fruit tree buds in relation to orchard heating, found that the internal temperature of an apple bud was uniformly lower than the temperature of the surrounding air during a frost in the dormant period when flame heaters were alight. The temperatures inside the bud are lowered by evaporation owing to the drying effects of the heaters. He considers that the effective distribution of heat depends largely upon the directive effects of slight downward flowing katabatic winds, for on still nights the rise in temperature even 5 ft. away from the source is only 4°F.

He shows that when non-humidified heat (i.e. flame heaters) was used in an experimental orchard the orchard temperature rose from 33·8°F. to 36°F. within half an hour, whereas the internal bud temperature fell from 32·2°F. to 28°F. When—in the absence of flame heaters—the air was humidified by the use of small bonfires composed of balls of wet pulped newspaper soaked in oil and covered with piles of wet grass, the bud temperature remained steady. Though the orchard heat was not raised so high as with flame heaters, the temperature within the bud did not fall. The expenditure of oil was very much less.

Coke is sometimes used for heating in California. The braziers hold 40 to 60 lb. and burn at the rate of 7 lb. per hour. To economize fuel during short frosts small wire baskets holding 13 lb. of coke are hung in the braziers. Coke gives more radiant energy than oil, a fact which is of benefit at night when there is no ceiling. It is ignited by pouring heater oil over it and kindling wood is not required. (Johnson, 1940.) In Germany briquettes of brown coal are used.

No published reports on the use of coke heaters in England are available. A coke heater was tried on a very minor scale at East Malling in the winter of 1936-7 but the experiments were not continued. Preliminary tests indicated difficulty in lighting and in quick production of heat.

13. SMOKE SCREENS AND CHEMICAL MISTS

The general conclusion seems to be that smokes and chemical mists may be of some value in light frosts but will not raise the temperature by more than about 2·7°F. The fact, however, that these methods have been used for many years on the European mainland, chiefly in vineyards, indicates a certain degree of success.

These smokes have all been produced at ground level. Production at high level as from an aeroplane still has to be tested. In this connection the opinion of Brunt, which is given below, is not particularly encouraging, but presumably only experiment can decide.

A brief review of the more recent foreign work on ground smokes and mists is somewhat inconclusive.

In France a portable apparatus has been evolved and patented known as P.N.B.33 which releases heavy gas clouds by chemical reaction of acid and base at a (pre-war) cost of 300 francs per night to cover 12 to 24 acres. It is harmless to plant and animal life, in fact, the sulphate of ammonia in the gas is reputed to have a beneficial effect on plant growth. The makers are the Société Anonyme des Forges et Fonderies de Pont à Mousson, Belleville, Meurthe et Moselle (Bret, 1933).

In other apparatus made by the Société Industrielle de Tourcoing the cloud is formed by two liquified gases, one of which acts as base, and the smoke finds itself neutralized by the same reaction which produced it. The apparatus is on wheels, weighs only 90 kg. and is simple to use. The gases are in cylinders containing an hour's supply and are easily replaced (Bret, 1934.)

Reports on both these machines were issued in 1933. Geslin (1935) in France dismissed them as not being a serious protection against frost, since the utmost they could achieve was a rise of 2·7°F. In 1939 Delmas (1939) in North Africa said that the usefulness of smoke screens was not proved, owing to the dissipating effect of wind.

In 1931 (Ext 1931) a cheap preparation was manufactured at Kiel in Germany by the Hanseatische Apparatebau Gesellschaft which produced a 60% H_2SO_4 cloud, which at 10-20 mg. per cu. metre was thick enough to hinder frost for several metres round the plants without damage to those with tender leaves, provided the apparatus was 100 m. distant. Its effect on fruit blossom was not tested and exact data of its performance are not available.

In 1928 Kessler (1928) in Germany suggested that artificial smoke could be distributed by aeroplane, especially in valleys. He also reports ground experiments at Oppenheim in which a large valley area was filled with smoke from burning naphthalene 3 parts and tar 1 part, in American-type heaters, distributed 80-120 to the acre. The temperature in the valley was maintained at 28·4°F. while outside it fell to 21·2°F. The smoke, however, was so impenetrable that even the trains could not run and a thick deposit of soot covered everything.

In 1934 Kessler (1934) again reports experiments carried out by the German Ministry of Agriculture in which acid clouds and ammonium chloride clouds gave excellent protection against frost on flat, but not on hilly ground. He gives no details, however, as to temperatures. In 1935 Kessler (1935) in a report on research on frost control in Germany decides that orchard heating (by brown coal briquettes) is more effective than smoke or chemical mists.

Schlenz (1939) in Germany found chemical mists effective in protecting the blossom from the early morning sun. When the temperature fell to 28°F. outside the chemical mists could raise it to 30°F. within the orchard but no higher.

The Fruitgrower (1944) gives details of a German fog generator said to have been used in Germany with great success before the present war. The manufacturers, IFFA, G.M.B.H., Berlin, issued a leaflet from which the following notes are taken. They begin with the statement that the Weather Bureau at Hamburg and the German Committee on Frost Protection at Trier have demonstrated that a mean drop in temperature of 8°F. above a fog blanket corresponds to a mean drop of only 2° below the blanket and that the lack of a blanket of clouds can be effectively supplied by a blanket of artificial fog. They then describe their appliance, but give no data of its performance beyond saying that it is successful. This fog generator consists of two parts: a lime container and a "fog acid" barrel. The lime container, a cylindrical sheet-metal vessel (size not given) is filled with walnut-sized lumps of burnt lime and covered against weather by oil paper clamped on with metal hoops. The acid barrel is

held to the lime container by means of 2 "feet" attached to these hoops. The acid barrel having a content of 7 imp. gal. is filled with 6½ imp. gal. of fog acid, being a solution of sulphur trioxide in chlorosulphonic acid. Screwed into the filler opening of the barrel is the nozzle head, containing three apertures each closed by a cap; (1) main nozzle, (2) auxiliary nozzle, (3) air inlet pipe. The nozzle head is guarded against injury and fouling by a screw cap. To operate the generator the plug is taken out of the barrel and the caps of (1), (2) and (3) are removed with a socket wrench. The acid barrel is then turned to bring the nozzle head down. The acid, now running from the barrel through the main and auxiliary nozzles, sprays upon the lime in the container, the oil paper covering being torn or perforated. The auxiliary nozzle is only for increasing fog generation at the start and is automatically shut off twelve minutes after the start, leaving the flow of acid to be effected by the main nozzle alone. The generation of fog can be cut off at any moment by turning the barrel with the nozzle up. One filling lasts five hours. The generators are set 100 ft. to 160 ft. apart up wind and, if the wind changes, they must be moved or fresh generators started.

In Austria, near Vienna, Schmidt (1929) claims to have prevented up to 60% of radiation loss by the use of smoke specially laden with moisture derived from large fires made up of tarry substances on to which horse dung was thrown. Incidentally, by smoke clouds from a large number of small burners distributed over the area and containing only the tarry substances he achieved a successful protection against 3·6 to 4·5°F. of radiation frost (thermometer readings 28·4°-27·5°F.). He points out that all such treatments must cover a large area to be fully effective.

In Holland (Zweede, 1934) experiments at the fruit research station at Wageningen confirmed the fact that in calm weather and mild frost a large number of small heaters could usefully raise the temperature above the danger point, but also showed that protection afforded by smoke was much less and that to have any effect smoke had to be applied over a large area.

Among the material tested peat dust soaked in crude naphthalene gave a very satisfactory heat and a thick sooty smoke.

(Grainger's results with humidified smoke are discussed under orchard heating, p. 13.)

So far, no country has experimented with the spreading of a smoke screen by aeroplane well above the fruit area. This carried out on frosty nights would be far less offensive to the inhabitants of the district than ground smoke and a test of its efficacy should certainly be made. The question was referred to Professor D. Brunt of the Department of Meteorology, Imperial College of Science and Technology. The relevant parts of his reply are quoted below. ". . . The difficulty which arises in applying such screens for fruit protection is that a tremendous installation of smoke apparatus and of aircraft is required to cover a relatively small area of ground. Even if the screen is only laid at 100 ft. above the ground it is exposed to a more rapid airflow than if it were on the ground and that in itself demands the use of far more smoke producing material. . . . The reason why I oppose the use of smoke on the ground is that the smoke itself would effectively radiate almost as much heat as solid ground would do when exposed to the clear sky, and the air cooled by the smoke would of necessity settle down and affect the crop which the smoke was meant to protect. If the smoke is at a height of, say, 100 ft. above the ground you will still have a fairly rapid cooling of the air containing the smoke when the sky is clear and if there is little or no wind the cooled air will tend to subside to the ground. The actual loss of heat would then be shared out through a layer of air extending from 100 ft. up, down to the ground. In theory, therefore, this appears to offer a more hopeful attack on the frost problem than the old method of laying smoke on the ground. Nevertheless I come back to the view expressed earlier that a very large installation would be required, and I should very much doubt whether the use of aircraft for such a purpose would be allowed as a normal procedure."

IV. THE PRESENT POSITION

So much, then, for investigations already made into reasons for frost damage and methods of prevention.

Much has been discovered, but results of immediate practical value to the deciduous fruitgrowing community have been few. The existence of frost pockets has been rediscovered,

but those fleeing to the hills soon realize that hilltops have their dangers too. Again, it has been found possible to heat orchards successfully, but it has not as yet been proved good economics. We know that mists and fogs check radiation, but can they be generated economically ? And, to be effective for the fruitgrower's purpose, will they be suffered gladly or at all by the non-fruitgrower ?

It must be emphasized that quick practical results cannot be expected from fundamental physiological and biochemical investigations, except in so far as they may possibly be able to furnish rapid tests of frost resistance. The physiologists are emphatic that the elucidation of the nature of frost resistance is a long term problem (Blackman, 1945). Such resistance probably depends on a complex of factors—on some delicate balance in the cell. Great difficulty has been found in getting an insight into physiological resistance to fungal disease and the same is likely to hold with frost resistance. Moreover, even if we do learn something of the nature of frost resistance, it does not follow that we shall therefore be able to control resistance.

It seems to us that if frost control can be achieved, it will most likely be by the combined efforts of meteorologists and pomologists. Some of the problems which they would be most qualified to solve and, in so doing, ease the fruitgrower's burden are set out below.

V. SUGGESTIONS WITH REGARD TO FUTURE WORK with a note on specific control methods

Investigations which would be of interest to fruitgrowers seem to fall under three main headings, although these cannot be rigidly separated.

Meteorological.
Topographical.
Pomological.

1. METEOROLOGICAL

(*a*) **Frost**

We need to know more regarding the distribution of frost in space and time under varying conditions.

Since 1935, when the frost of 16th-17th May wiped out a large proportion of the fruit in England, much has been learnt about what happens on a cold, clear, still night. But what we have not learnt and what we want to know more about are the circumstances when frosts occur under other conditions, e.g. where there is wind of more than, say, five miles an hour, or when the frost is accompanied by rain or snow. This knowledge must be combined with some idea of the frequency of occurrence of such frosts at critical times of year and their relationship to topography, e.g. whether they are associated with winds only from certain directions, if use is to be made of the knowledge in siting future fruit plantations. When they do come, there seems at present little possibility of mitigating them.

(*b*) **Wind**

Before fruitgrowers migrate to the hills the study of hilltop winds is essential. Can such winds be utilized as suggested by Cornford (1938) for the prevention of frost damage on the hill tops ? Might not, as he suggests, microclimatological observations form the basis of a method for combating wind frosts? Much information is wanted on bud temperatures, local airflows, etc.

How are windbreaks to be constituted and how placed so as to protect the orchard when necessary and yet not defeat the object of higher plantings by creating just the conditions with regard to frost, i.e. stagnant cold air, that we want to avoid ?

2. TOPOGRAPHICAL

We also must know more of the detailed effects of topography and the nature of the soil surface and its plant cover on frost distribution.

Situations in which fruit is or may be grown are of three kinds, namely, true frost holes, broad valleys or plains and hilltops.

(*a*) **Frost holes**

Frost holes may occur at any altitude. They are usually small valleys or depressions either naturally or artificially created, sheltered from high winds, but with restricted or no outlet for cold air flowing into them. They are subject to frost on most occasions when cold, clear, calm conditions prevail. They are generally unsuitable for fruit growing and are probably now sufficiently well recognized to be avoided. They are probably more suitable for the use of orchard heaters than most other situations. (See also note on orchard heating, p. 18.)

(*b*) **Broad valleys or plains**

Most of the best fruit growing soils are to be found in broad valleys or plains, such as the Weald of Kent and the whole of the Cambridgeshire fruit area. Therefore a large proportion of the present day fruit growing areas are to be found therein and in many instances have been there for a very long time. They are subject to both " radiation " and " wind " frosts, but these are only severe when exceptionally cold conditions prevail over the whole country. It is very difficult to see how such sites can be avoided, if fruit growing acreages are to be maintained or even extended.

The fact that fruit has been grown successfully in such areas for so long seems to indicate that the occurrence of these severe frosts at a time harmful to fruit blossoms is not excessively frequent. In this connection data obtained over a long period in suitable situations are interesting. Thus, at Rothamsted in the 67 years to 1945, there were 51 occasions in April when the temperature in the screen fell to 26°F. or lower but only 4 in May. A study of such records in relation to the topography of the Stations where they are taken might well be made before judging too much from the record of the last ten years.

The mitigation of these severe frosts when they do occur is very difficult and probably can only be done on a large scale—a number of growers co-operating together for the purpose. It is possible that some of the wartime research in relation to aerodromes may give some hint of an economic method ; but whether such a method can be devised which is cheap and which can be brought into operation quickly on any night over a considerable period of time and which moreover may not be needed at all for years on end, seems rather doubtful.

(*c*) **Hilltops**

A grower who wishes to develop fruit on a large scale on the hilltops or the higher hillsides will have to contend with (*a*) wind, (*b*) possibly unsuitable soil conditions and even erosion, (*c*) occasional " wind frosts ". Wind has already been discussed. Apart from this, if these areas are to be developed, a detailed soil survey should be initiated in districts otherwise suitable (e.g. rainfall), to find suitable sites in which fruit can be successfully grown. It seems probable that these areas will be limited in extent. But at present there appears to be no happier advice on wind frosts than to grin and bear them.

3. POMOLOGICAL

Here there are two main lines of research which may help to mitigate the effects of frosts, if not prevent them altogether. These are (*a*) Breeding (i) for late blossoming varieties, (ii) for varieties inherently resistant to low temperature, and (*b*) Cultural methods.

(*a*) **Breeding**

(i) For late blossoming. Both aims of the breeder entail long term projects. Late blossoming varieties can be at best only a partial solution of the problem, for there will be early seasons when they may be in an even more susceptible condition when the frost occurs than the early blossoming kinds. Thus, in at least one spring frost year at East Malling early blossoming varieties of apple got through better than late blossoming varieties (East Malling, 1942). Nevertheless, in breeding early blossoming is probably a character to avoid. The use of a proportion of late blossoming varieties might well be recommended on all farms as a form of insurance as an immediate measure.

(ii) For resistance. The last ten years have shown quite marked differences in susceptibility of varieties which blossom at the same time. The breeding of resistant varieties and the gradual elimination of varieties which show marked susceptibility is therefore a definite possibility. To be successful, however, it is first necessary to find the reasons for susceptibility or resistance. An intensive onslaught on this problem is most desirable and it should include very detailed morphological, physiological and chemical studies of certain varieties, e.g. of Bramley and Worcester apples; Czar and Victoria plums, Conference and others of the more susceptible pears, though in pears the problem is rather different. This investigation might well be combined with a study of cultural methods.

(*b*) **Cultural methods**

Many unexplained instances of particular resistance or susceptibility in the past lead to the conclusion that cultural conditions do modify, at least to some extent, the reaction of varieties to frost. Of these, conditions which induce biennial bearing may be important. Thus in Canada it was shown that varieties which had just cropped very heavily were particularly liable to winter injury. Does this apply also to the flowers in the following spring? If so, it might indicate that any cultural treatment which induces a similar condition in the trees may have the same effect. For some years there have seemed to be certain predisposing conditions (e.g. possibly a warm dry autumn) which conduce to a "pear" year. In such years blossoms are bolder—are they also more resistant to frost? Thus, in 1944 at East Malling there was every indication at blossoming time of another "pear year" and indeed, despite severe frost, many varieties besides Conference developed their fruit, though seedless. Why did the Czar plums on young trees set in 1944, whereas on others much older but in rather poor condition they did not? Was it because of youthful vigour as against the old age or rather poor condition of the older trees? These problems may well link up with that of spray injury.

Broadly speaking, the aims of cultural methods will be to discover (1) what cultural conditions make trees more susceptible to frost injury—and avoid them, (2) cultural devices for making trees less susceptible, e.g. artificial prolongation of dormancy—though this too has its limitations (see above on breeding for late blossoming)—and (3) methods of inducing commercially effective parthenocarpy in frosted flowers, see p. 9.

The pomologist aided by the plant breeder will be responsible for the cultural and breeding investigations. The broader, meteorological and topographical studies are no less necessary and should be the task of expert meteorologists, soil surveyors, etc. The pomologist will of course be associated with them but he cannot be entirely responsible.

VI. SPECIFIC CONTROL MEASURES

Two methods of frost damage prevention which have, under very different conditions to those obtaining in England, proved of value are orchard heating and the prevention of radiation by cloud production. It may be of use to touch on certain aspects of the application of these methods not discussed in previous pages.

1. ORCHARD HEATING

As noted previously true frost holes are probably the easiest situations in which to use orchard heating. But most fruit is not situated in frost holes and the great problem seems to be how, having generated a certain amount of heat, to keep that heat in the orchard. With the advance of knowledge, it may be possible to produce fuels which will not only be smokeless, but will also generate a much greater amount of heat per unit heater, and these in conjunction with suitably situated fans or propellors might solve the problem for large areas on the flat. But such a set up would in all probability be very expensive, both initially and to maintain, and it is very doubtful whether it would be economically worth while, especially as it may be of use on only one occasion in a number of years. Apart from the capital and maintenance expense of the apparatus, there is also the problem of having trained labour in readiness at short notice.

It is possible that some of the readers of this bulletin may have seen suggestions in the

Press on or about 1st June, 1945, when news of FIDO* was given to the public, that work had already been started by scientists on the adaptation of the process to orchard heating. One of these suggestions was followed up by the bureau, the final result being a letter from the Petroleum Warfare Department, the relevant portion of which runs as follows :—" There seems to have been some confusion of ideas in this matter, as no work has ever been done in the direction of applying F.I.D.O. equipment to protection against frost in orchards. It is possible that some confusion may have arisen by reason of reference being made to some earlier observations which were made on the effect of the ordinary standard orchard heaters in dissipating fog on a small scale ".

2. PRODUCTION OF SMOKE CLOUDS

Although expert opinion is that fog or cloud produced in contact with the ground is unlikely to afford protection (p. 13), the production of smoke clouds at, say, 100 feet above ground level may be worth further consideration.

The Chemical Defence Department of the Ministry of Supply, in the successful screening of Montgomery's army before its final advance across the Lower Rhine, has shown the possibility of forming screens above the ground. Such screens, being of a chemical nature, might well be less objectionable than oil smoke and do no harm to fruit.

Surely their possible use in the orchard, produced by ground apparatus or by aeroplane merits early investigations ?

The costs involved would probably be very high and possibly prohibitive.

Nevertheless, appropriate experiments would be worth while—before the materials and experts are dispersed—if only to answer such questions as : Would such clouds be effective ? On what scale could they be produced ? and, if so, what would the cost be ?

ACKNOWLEDGMENTS

In compiling this bulletin the bureau is greatly indebted to Professor E. J. Salisbury not only for his foreword but for his much appreciated constructive criticism.

It is equally grateful to many others for help and advice, notably Professor V. H. Blackman, Professor D. Brunt, Mr. T. N. Hoblyn and Dr. T. Swarbrick.

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* Fog investigation dispersal operations. The device and apparatus whereby, under conditions of dense fog, aeroplanes were enabled to land on aerodromes cleared of fog by the heat afforded by a continuous line of burners installed parallel to and some distance from each side of the main runway, *see* daily newspapers of Great Britain on 1st June, 1945.

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